CLOUDS AND THE EARTH'S RADIANT ENERGY SYSTEM (CERES)

VALIDATION PLAN

ERBE-LIKE AVERAGING TO MONTHLY TOA FLUXES (SUBSYSTEM 3.0)

Takmeng Wong

David F. Young

Patrick Minnis

Gary G. Gibson

Atmospheric Science Division
NASA Langley Research Center
Hampton, Virginia 23681

Release 4.0
August 2000

CERES VALIDATION PLAN

3.0 ERBE-LIKE AVERAGING TO MONTHLY TOA FLUXES

3.1 INTRODUCTION

3.1.1 Measurement and science objectives

A major emphasis of radiation budget research is on the monitoring and analysis of long-term variations in the Earth-atmosphere climate system. This can only be accomplished using stable, long-term global data sets. The chief science objective of the CERES (Wielicki et al., 1996, 1998) Subsystem 3 is to fulfill this research need. Specifically, this subsystem will provide averages of top-of-atmosphere (TOA) radiative parameters from CERES scanner measurements of shortwave (SW) and longwave (LW) flux using a data processing system consistent with the earlier Earth Radiation Budget Experiment (ERBE; Barkstrom 1984).

3.1.2 Missions

The CERES instruments will be flown on multiple satellites, which include TRMM, Terra, and Aqua, to provide the diurnal sampling necessary to obtain accurate monthly averages of the TOA radiative parameters.

3.1.3 Science data products

The CERES ERBE-like processing algorithm produces three different science products. They are ERBE-like Science Product 4 (ES-4), ERBE-like Science Product 4 Gridded (ES-4G), and ERBE-Like Science Product 9 (ES-9). Each of the science products contains temporally and spatially averaged CERES scanner estimates of the upward SW and LW flux at the TOA. The ES-4 and ES-4G are regional (i.e., 2.5-degree equal-angle grid), zonal, and global average products arranged temporally to days, monthly-hours, and the month. Furthermore, ES-4 and ES-4G are identical products except in arrangement of the data. While the ES-4 science product is arranged by region, the ES-4G file presents a gridded data product with all regions for a given data parameter grouped together. The ES-9 is a product of regional (2.5-degree) average only. The data in the ES-9 product are stored by the hour for each hour of each day in the month. There are 77, 74, and 243 data parameters in the ES-4, ES-4G and ES-9 science products, respectively. These include the mean estimates of SW and LW radiant flux at the TOA, the standard deviations of these estimates, the maximum and minimum estimate, and scene information or cloud condition. The complete list of these data parameters can be found in the CERES Data Products Catalog (this can be accessed at the CERES on-line documentation web site at http://asd-www.larc.nasa.gov/ceres/docs.html).

In the next section, we will outline the method adopted by the CERES Time Interpolation and Spatial Averaging (TISA) working group for validating these ERBE-like data parameters. Section 3.3 will concentrate on pre-launch validation. The post-launch activities, including validation results from the first 8 months of TRMM, will be described in section 3.4. Section 3.5 will discuss the implementation of the validation data sets in data production. A final summary is given in section 3.6.

3.2 VALIDATION CRITERION

3.2.1 Overall approach

The ERBE-like data processing system algorithm is very similar to those used by ERBE. Specifically, it uses a comprehensive set of LW and SW angular dependence models to convert radiances to fluxes. In addition, special averaging procedures are used to produce monthly mean of TOA radiative parameters on various spatial and temporal scales. Details of this science algorithm can be found in the CERES ATBD documents (found at http://asd-www.larc.nasa.gov/ceres/docs.html). The input into this subsystem includes CERES scanner observations of SW and LW TOA flux, satellite viewing geometry, latitude and longitude of the measurement, the underlying geographic scene type, cloud amount information, TOA albedo angular dependence models (ADMs), and solar declination. The output from this subsystem consists of daily, monthly-hourly, and monthly means of TOA SW and LW flux on regional, zonal, and global scales.

The validation of the ERBE-like subsystem is an integral part of the CERES system. The purpose of this validation is to thoroughly test the subsystem and detect possible problems or errors. This activity includes the validation of both the ERBE-like science algorithms and the ERBE-like science data product. The ERBE-like science algorithms are declared to be completed and validation activities will cease if the following criteria for the science algorithms are satisfied:

1. The technique in the science algorithms is finalized (i.e., completing pre-launch science studies).
2. The accuracy criteria of the science algorithm are met.
3. The data processing system is completed (i.e., verifying input/output operations and interface compatibility with other subsystems).
4. No reprocessing of the science data product is recommended.

If these criteria are not met, the validation of the science algorithm will continue. The validation criteria for the science data product are similar to those given by the science algorithm. Specifically, the science data product is declared to be valid if the following two criteria are met:

1. The science data product can be verified from independent data sources of known precision and/or accuracy.
2. The science data product does not violate known physical principles.

Unlike the science algorithms, this validation activity will not stop after the initial verification of the data product. On the contrary, validation of the ERBE-like data product will continue as long as input data is available. This activity is necessary in order to maintain continuous monitoring of the quality of the input data product and to detect problems/errors in the overall system.

In order to conserve resources, the CERES TISA working group will not be validating every single data parameter listed in each of the ERBE-like science products. Instead, the TISA working group will concentrate on a few of the most important data parameters. These parameters include 1) the LW and SW TOA total-sky flux, 2) the LW and SW TOA clear-sky flux, and 3) the ERBE-like scene identification.

3.2.2 Sampling requirements

In order to validate ERBE-like data products, we will require a minimum of six months of data from each of the CERES satellites. Additional data months are also required to perform data consistency tests between different satellites (i.e., TRMM against Terra, TRMM against Aqua, and Terra against Aqua).

3.2.3 Measures of success

Several studies of the ERBE error sources (i.e., Harrison et al., 1990 and Young et al., 1998) have resulted in reliable estimates of the uncertainties in monthly mean TOA LW and SW radiation due to time sampling issues. The results of these studies for the single-satellite TRMM product, along with the CERES science requirements, are outlined in Table 1. Estimates are made for clear-sky and all-sky conditions. Overall, time-sampling errors in the monthly mean TOA radiative parameters are expected to be smaller for the CERES 3-satellite configuration. Bias errors for regional fluxes are estimated to be 0.5 and 2 Wm^{-2} for the LW and SW fluxes, respectively. The rms uncertainties in LW and SW fluxes are on the order of 1.5 and 5 Wm^{-2}, respectively.

Table 1: Time Sampling Error Estimates for ERBE-Like Monthly Mean Regional Fluxes for Single Satellite Products (Wm^{-2}).

Parameter	Clear-sky Bias Error	Clear-sky RMS Error	All-sky Bias Error	All-sky RMS Error
TOA SW_{up}	2	5	3	8 - 11
TOA LW_{up}	1	2	2	2 - 5
Science Requirement	2 - 5	10	2 - 5	10

In order to approach the validation activity in a systematic matter, the CERES Science Team has adopted a two-step process for validating this subsystem. This process can be broken down into the pre-launch and the post-launch validation. This is necessary due to the nature of the monthly mean products. Post-launch validation studies that compare CERES monthly mean products with validation data sets cannot isolate errors due specifically to time-sampling. Monthly mean products will include errors from all aspects of the CERES data reduction system. These errors must be resolved using sampling theory with high temporal resolution data sets. This is part of the pre-launch validation effort. The details of the pre-launch and post-launch validations are outlined in the next two sections.

3.3 PRE-LAUNCH ALGORITHM TEST/DEVELOPMENT ACTIVITIES

3.3.1 Field experiments and studies

N/A

3.3.2 Operational surface networks

N/A

3.3.3 Existing satellite data

The two objectives of the pre-launch activities are to 1) validate the methods and algorithms used in the production of ERBE-like science data product and 2) to assess the errors due to temporal sampling using high temporal resolution data sets. In order to achieve the first of these goals, the CERES's TISA working group has implemented the following procedures for pre-launch testing of the ERBE-like science algorithm:

1. All required input data for the subsystem are collected.
2. Science algorithm of the subsystem is used to process the input data.
3. Output data from the subsystem are verified against known results.
4. Retesting of the improved science algorithms is required if the original science algorithms fail during the processing stage or the final outputs fail to verify against known results.

Since large portions of the ERBE-like data processing software are based on the successful ERBE method, the pre-launch algorithm testing of this subsystem is based mainly on input from existing ERBE TOA scanner data set. The algorithm was tested using two data sets. First, the code was run using several months of actual ERBE data. The algorithm reproduced all ERBE mean fluxes to within 0.1%. Secondly, a simulated CERES data set produced by over-sampling ERBE data from October 1986 was input into the data system to test the data input interface with the other CERES subsystems. This test demonstrated that the subsystem is performing properly.

The second goal of determining the errors due to temporal sampling was also completed prior to launch. The results of these activities are reported in the CERES ATBDs and in Young, et al. 1998. In summary, the temporal errors were calculated by temporally sampling GOES data and comparing monthly means computed from these data with means from the complete time series, SW and LW rms monthly mean errors for TRMM are <11 Wm^{-2} (<12%) and <5 Wm^{-2} (<2%), respectively. Bias errors for LW are < 0.5 Wm^{-2}. For SW, mean biases can be $3Wm^{-2}$ depending on the particular TRMM sampling pattern for the month. RMS errors for Terra and Aqua are generally less than for TRMM, although biases can persist in regions with well-defined diurnal cycles. Combined satellite products reduce sampling errors by a factor of 2-3.

As part of the pre-launch activities, several operational products that will be used in validating the CERES ERBE-like data have been designed and implemented. These products include:

1. Time series plots of radiation parameters over a pre-selected set of validation regions, latitude zone, and the globe.
2. Zonal and global averaged monthly mean images of these parameters.
3. Two dimensional error analyses results of the data product (if available).

These images are available to members of the CERES Science Team immediately following production of ERBE-like products via a Web site. The time series plots will be produced for the 283 regions identified by CERES as validation sites. These regions, which cover a wide range of climatic regions and a number of EOS and CERES surface validation sites, will be useful in testing the overall robustness of the ERBE-like algorithm in handling data for various scene types and cloudiness conditions. The special validation output product will be used to identify and to record problematic areas associated with the ERBE-like data product.

Finally, the last stage of the pre-launch algorithm testing involves algorithm development activities. The purpose of this stage is to correct any systematic problems that have been encountered during the pre-launch testing period. Improved science algorithms are also continually being developed and tested. Any proposed changes to the algorithms will be tested thoroughly in the manner described above before being implemented. The Science Team has also decided that any improvement to the ERBE-like algorithm must also be implemented in a reprocessing of the historical ERBE data in order to maintain algorithmic consistency between the two data sets.

3.4 POST-LAUNCH ACTIVITIES

3.4.1 Planned field activities and studies

N/A

3.4.2 New EOS-targeted coordinated field campaigns

N/A

3.4.3 Needs for other satellite data

The post-launch validation will concentrate on examination and verification of the ERBE-like results. Specifically, the main purpose of these activities is to determine whether the ERBE-like results are qualitatively acceptable and agree well with expected quantitative results derived from other independent data sources. The CERES TISA working group has tentatively adopted the following procedures for the post-launch validation activities of the ERBE-like data products:

1. CERES TOA scanner data sets are collected during intensive initial validation period as input into the data processing system.
2. Independent data sets that match the initial validation period are collected for intercomparison studies.
3. Intensive initial validation of the output data against the independent data sets is performed to ensure accuracy and consistence of the output results.
4. Continuous quality control of the input data sets and constant monitoring of the output data will be implemented after the intensive initial validation period to detect problems/ errors in the overall system.

The intensive initial validation is tentatively scheduled after the ingestion of each of the following data sets and the completion of their corresponding validation data:

1. First full month of CERES scanner data.
2. First full season of CERES scanner data.
3. First full year of CERES scanner data.

Three separate sets of these validation activities, corresponding to each of the CERES satellite data sets (i.e., TRMM, Terra, and Aqua), will be executed.

During the intensive initial validation, a thorough error analysis and time series studies will be performed to assess the quality of the new ERBE-like data set. A special validation output similar to that outlined for the pre-launch validation will be produced to aid the validation activities. A number of independent data sets will be needed for the intensive validation of the ERBE-like TOA product.

A schedule of post-launch validation studies that will be performed for the ERBE-like products is given in Table 2. These activities include:

1. Comparison of monthly mean LW and SW fluxes and scene identification from CERES and historical ERBE ERBS scanner data. The emphasis of this study will be on comparisons of tropical mean fluxes (defined as the average of all regions between 20 Nand 20 S) in order to minimize temporal sampling differences. This comparison has already been completed for the first eight months of TRMM CERES ERBE-like data, which have been compared with the ERBS scanner data from 1985-1989. The main results include:

- Total-sky LW flux - CERES LW fluxes are 5-10 Wm^{-2} (2-4%) higher than ERBE. The difference maximizes in February, which is also the maximum of the 1998 El Niño event. The difference is minimized in July when El Niño has essentially disappeared. A similar increase in total-sky LW flux from 1985-1989 to 1998 is also seen in the ERBS non-scanner data.
- Clear-sky LW flux - The CERES clear-sky LW fluxes are 1-3.5 Wm^{-2} (0.3-1.2)% higher than ERBE. This difference also maximizes in February and minimizes in July. The differences have been shown to be consistent with variations in sea surface temperature and atmospheric humidity associated with El Niño.
- Total-sky SW flux - The difference between CERES and the 5-year mean ERBE data varies between +0.3 and -5 Wm^{-2} (+0.3 and -5%). However, the 2 standard deviation bound for the month-to-month temporal sampling variability of the total-sky SW tropical mean for this time period is 5%. Therefore, the observed difference is within the temporal sampling error limits.

Table 2: CERES ERBE-like Validation Schedule.

Year	**1998**				**1999**				**2000**				**2001**				**2002**			
Quarter	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**
TRMM vs. ERBS scanner			x																	
TRMM vs. non-scanner			x																	
TRMM vs. ScaRaB						x														
TRMM directional models		x																		
TRMM RAP vs. FAP			x																	
TRMM vs. GGEO							x													
Terra vs. ERBS scanner											x									
Terra vs. non-scanner											x									
Terra directional models										x										
Terra RAP vs. FAP											x									
Terra vs. TRMM										x										
Aqua vs. ERBS scanner															x					
Aqua vs. non-scanner															x					
Aqua directional models																x				
Aqua vs. Terra																x				
Multiple vs. single satellite																		x		

- Clear-sky SW flux - The difference between CERES and ERBE in clear-sky SW flux varies with geographical scene type. CERES fluxes are on the average 0.8 Wm^{-2} (1.8%), 4.1 Wm^{-2} (6.1%), and 7.3 Wm^{-2} (8.7%) lower than ERBE for ocean, land and desert regions, respectively. In January, the clear ocean difference can be reduced from -1.5 Wm^{-2} to +0.2 Wm^{-2} when the CERES spatial resolution is reduced to simulate the ERBS field of view. The land and desert differences are reduced only slightly by changing the spatial resolution. The archived ES9 product was produced using the full resolution CERES data.
- Scene identification - In general, CERES classifies more footprints as clear than ERBE. This difference is also greatest in February with CERES classifying 33% of the observations as clear, while ERBE classifies only 20% as clear. The difference in July

is decreased to 22% vs. 16%. Much of the remaining difference can be attributed to the smaller CERES footprint size.

2. The CERES ERBE-like data have been compared with ERBS non-scanner data for verification of calibration. Tropical monthly mean ocean total-sky LW fluxes have been averaged for all available months of ERBS scanner (1/85 - 12/89), ERBS non-scanner (1/85 - 2/98), SCARAB scanner (3/94 - 2/95), and CERES scanner (1/98 - 2/98) data. Scanner - non-scanner differences for each of the 3 scanners agree to < 1%. In addition, instantaneous CERES ERBE-like fluxes have been compared with ERBS non-scanner data. Comparisons using data from January through August 1998 have demonstrated agreement to within 0.1% for both SW flux, 0.5% for nighttime LW flux, and 2.5% for daytime LW flux.
3. Comparisons with contemporaneous ScaRaB data. The CERES and ScaRaB Science Teams have worked closely to insure that contemporaneous, well-matched data were collected from the two instruments during the period of concurrent operation. Tropical monthly mean flux and flux histograms from CERES and ScaRaB have been compared. Comparisons from 1998 have demonstrated agreement in LW radiance to within 1% at night and 2.5% in the day. Comparisons of monthly mean fluxes will be performed when the ScaRaB results become available.
4. Comparisons of empirical directional models of albedo as a function of solar zenith angle constructed from ERBE ERBS scanner and CERES scanner data. Using the ERBE twelve scene types to classify the data, no statistically significant differences occur between models developed from 60 months of ERBS data and the first 8 months of CERES TRMM data.
5. Comparison of time-averaged CERES crosstrack and rotating-azimuth fluxes. The goal of this study is to establish the consistency of spatially gridded data from the two scanning modes. Biases between these two data sets would preclude the use of both in the calculation of monthly mean fluxes. For TRMM, six months of instantaneous rotating azimuth plane (RAP) and crosstrack fluxes have been averaged as a function of SZA and scene type. These fluxes agree to <1% in all cases with no statistically significant biases. Seasonally averaged regional fluxes computed from crosstrack data alone and combined RAP and crosstrack data also show no systematic biases. The dual CERES scanners aboard Terra allow a more thorough investigation of this aspect of the data. Monthly means made strictly from cross-track data can be compared directly with means from rotating azimuth data. Initial comparisons of instantaneous regional averages of RAP and crosstrack data from the first month of Terra data reveal no biases in the SW and LW fluxes.
6. Comparison of the monthly mean clear-sky LW fluxes from CERES with radiative transfer clear-sky LW simulations. The purpose of this exercise is to check for consistency between CERES observations and theoretical results with given background meteorology. Radiative transfer simulations have been performed for the first seven months of 1998 with the corresponding inputs from NOAA/NCEP three-dimensional atmospheric thermal

and moisture data product and NOAA Reynold's SST data product. Results of the comparison with the first seven months of TRMM CERES ERBE-like clear-sky longwave fluxes yield excellent spatial and temporal agreements between TRMM CERES observations and theory. These results offer additional theoretical support that the observed CERES clear-sky LW fluxes are consistent with the physics of the observed background atmosphere.

7. Finally, the CERES TISA working group plans to use 1-hourly (if available) and 3-hourly geostationary data (i.e., GOES-8, GOES-9, METEOSAT, and GMS) as a source for validating ERBE-like sampling errors. In order to facilitate intercomparison between the two data sets, the narrowband radiances on the geostationary satellites will be converted to broadband fluxes using narrowband-to-broadband conversion relationships and angular dependence models. In addition, the CERES TISA working group will be acquiring data, if available, from the new European Geostationary Earth Radiation Budget (GERB) for direct TOA flux intercomparision.

After the intensive initial validation is completed, the CERES TISA working group plans to continue monitoring the quality of the input data set and to correct any problems associated with the overall ERBE-like subsystem. Special validation output product will be used extensively during this period. This activity will continue as long as input data are made available to this subsystem.

3.4.4 Measurement needs (in situ) at calibration/validation sites

N/A

3.4.5 Needs for instrument development

N/A

3.4.6 Geometric registration site

N/A

3.4.7 Intercomparison

After the launch of the Terra and the Aqua satellite, the new CERES radiation data set can also be validated by comparison with special validation data products from the TRMM satellite. Terra can also be compared with Aqua data. Plus, ERBE-like products produced independently for the two scanners aboard Terra can be compared. This will be particularly important for months where one scanner works throughout the month in crosstrack mode while the other is continuously in rotating-azimuth mode. Finally, the CERES TISA working group also plans to perform intercomparisons of CERES multiple satellite products (such as TRMM+Terra) with single satellite products (i.e., TRMM or Terra).

3.5 IMPLEMENTATION OF VALIDATION RESULTS IN DATA PRODUCTION

3.5.1 Approach

The procedures for pre-launch and post-launch validation of this subsystem have been outlined in the previous section. The results of these validations should, in general, lead to further improvement in the quality of the CERES data set. Major problems discovered after data production will be recorded and techniques for resolving them will be developed. The new algorithms will remain consistent with ERBE. The correction of these problems will then be implemented during the CERES data reprocessing period.

3.5.2 Role of EOSDIS

EOSDIS will provide special processing of CERES ERBE-like data products for regions containing validation sites.

3.5.3 Plans for archival of validation data

The results of the validation and their associated problems will be stored at the NASA Langley Research Center. The user community can access this information either through an anonymous FTP account or through the use of World Wide Web browser technology. The results of the completed validation studies for the TRMM ERBE-like data have been included in CERES Data Quality Summaries that are available to all potential users via the Web at the following URL locations.

- ES-4 data product -- http://eosweb.larc.nasa.gov/HBDOCS/disclaimer_CER_ES4.html.
- ES-9 data product -- http://eosweb.larc.nasa.gov/HBDOCS/disclaimer_CER_ES9.html.

3.6 SUMMARY

This document describes a plan for validating the CERES ERBE-like data products. The validation plan is broken up into two stages; the pre-launch and the post-launch stage. A minimum of one year of data from each of the CERES satellites will be required to validate the data products. The validation efforts will be concentrated on a set of emphasized parameters. A set of special validation regions will be used to identify and to record problematic areas associated with the ERBE-like data product. EOSDIS will provide special processing of CERES ERBE-like data products for regions containing these validation sites.

Many of pre-launch activities have been completed to verify the ERBE-like algorithm using existing ERBE TOA scanner data. The results of these activities are reported in the CERES ATBDs. Additional pre-launch tests based on CERES system-wide end-to-end simulation using archival October 1986 ERBE data set are partially completed. The post-launch validation will employ comparisons with existing Earth Radiation Budget data sets and geostationary narrowband data to verify the ERBE-like sampling errors. In addition, data acquired from different CERES satellites can be used to validate each other. The results of the validation and their associated problems will be stored at the NASA Langley Research Center. The user community can access this information either through an anonymous FTP account or through the use of World Wide Web browser technology.

REFERENCE

Barkstrom, B. R., 1984: The Earth Radiation budget Experiment (ERBE). *Bull. Amer. Meteor. Soc.*, **65**, 1170-1185.

Harrison, E. F., P. Minnis, B. R. Barkstrom, V. Ramanathan, R. D. Cess, and G. G. Gibson, 1990: Seasonal variation of cloud radiative forcing derived from the Earth Radiation Budget Experiment. *J. Geophys. Res.*, **95**, 18687-18703.

Wielicki, B. A., B. R. Barkstrom, E. F. Harrison, R. B. Lee, III, G. L. Smith, and J. E. Cooper, 1996: Clouds and the Earth's Radiant Energy System (CERES); An Earth Observing System Experiment. *Bull. Amer. Meteor. Soc.*, **77**, 853-868.

Wielicki, B. A., B. R. Barkstrom, B. A. Baum, T. P. Charlock, R. N. Green, D. P. Kratz, R. B. Lee, P. Minnis, G. L. Smith, T. Wong, D. F. Young, R. D. Cess, J. A. Coakley, Jr., D. A. H. Crommelynck, L Donner, R. Kandel, M. D. King, A. J. Miller, V. Ramanathan, D. A. Randall, L. L. Stowe, and R. M. Welch, 1998b: Clouds and the Earth's Radiant Energy System (CERES): Algorithm Overview, *IEEE Transactions on Geoscience and Remote Sensing*, **36**, 1127-1141.

Young, D. F., P. Minnis, D. R. Doelling, G. G. Gibson, and P. Minnis, 1998: Temporal Interpolation Methods for the Clouds and the Earth's Radiant Energy System (CERES) Experiment. *J. Appl. Meteor.*, **37**, 572-590.